

THE NEXT GENERATION OF MARS-GRAM AND ITS ROLE IN THE AUTONOMOUS AEROBRAKING DEVELOPMENT PLAN

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The Mars Global Reference Atmospheric Model (Mars-GRAM) is an engineering-level atmospheric model widely used for diverse mission applications. Mars-GRAM has been utilized during the aerobraking operations of the Mars Global Surveyor (MGS), Mars Odyssey (ODY) and Mars Reconnaissance Orbiter (MRO) spacecraft and was part of the Mars Aerocapture System Study (MASS) as well as the Aerocapture Technology Assessment Group (TAG). Mars-GRAM 2010 is currently being used to develop the onboard atmospheric density estimator that is part of the Autonomous Aerobraking Development Plan. In previous versions, Mars-GRAM was less than realistic when used for sensitivity studies for Thermal Emission Spectrometer (TES) MapYear=0 and large optical depth values, such as $\tau=3$. A comparison analysis has been completed between Mars-GRAM, TES and data from the Planetary Data System (PDS) resulting in updated coefficients for the functions relating density, latitude, and longitude of the sun. Traditional Mars-GRAM options for representing the mean atmosphere along entry corridors include: (1) TES mapping year 0, with user-controlled dust optical depth and Mars-GRAM data interpolated from the NASA Ames Mars General Circulation Model (MGCM) results driven by selected values of globally-uniform dust optical depth, or (2) TES mapping years 1 and 2, with Mars-GRAM data coming from MGCM results driven by observed TES dust optical depth. Mars-GRAM is based from the surface to 80 kilometers (km) altitude on the NASA Ames MGCM. MGCM results that were used for previous versions of Mars-GRAM with MapYear = 0 were from a MGCM run with a fixed value of $\tau = 3$ for the entire year at all locations. This choice of data has led to discrepancies that have become apparent during recent sensitivity studies for MapYear = 0 and large optical depths. In determining a possible solution to this discrepancy, Mars-GRAM was evaluated at locations and times of TES limb observations and adjustment factors (ratio of observed TES density to Mars-GRAM (MGCM) density) were determined. Above 80 km, Mars-GRAM is based on the University of Michigan Mars Thermospheric General Circulation Model (MTGCM). For altitudes above 80 km and below 135 km, Mars-GRAM (MTGCM) densities were compared to aerobraking densities measured by MGS, ODY, and MRO. The adjustment factors generated by this process had to satisfy the gas law: $p = \rho RT$ as well as the hydrostatic relation: $dp/dz = -\rho g$. The adjustment factors $[F(z, Lat, Ls)]$ are expressed as a function of height (z), Latitude (Lat) and areocentric solar longitude (Ls). The latest release of Mars-GRAM (2010) includes these adjustment factors that alter the input data from MGCM and MTGCM for the Mapping Year 0 (user-controlled dust) case. The greatest adjustment occurs at large optical depths such as $\tau > 1$. The addition of the adjustment factors has led to better correspondence to TES Limb data from 0-60 km as well as better agreement with MGS, ODY and MRO data at approximately 90-130 km. Examples of improved atmospheric simulations for various locations, times and dust conditions on Mars will be presented at the conference session. Improved simulations utilizing Mars-GRAM 2010 are vital to developing the onboard atmospheric density estimator for the Autonomous Aerobraking Development Plan. Mars-GRAM 2010 was not the only planetary GRAM utilized during phase 1 of this plan; Titan-GRAM and Venus-GRAM were used to generate density data sets for Aerobraking Design Reference Missions. These data sets included altitude profiles (both vertical and along a trajectory), GRAM perturbations (tides, gravity waves, etc.) and provided density and scale height values for analysis by other Autonomous Aerobraking team members.

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INTRODUCTION

The Mars Global Reference Atmospheric Model (Mars-GRAM) has been utilized during the aerobraking operations of the Mars Global Surveyor (MGS), Mars Odyssey (ODY) and Mars Reconnaissance Orbiter (MRO) spacecraft and was part of the Mars Aerocapture System Study (MASS) as well as the Aerocapture Technology Assessment Group (TAG). Mars-GRAM's per-

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turbation modeling capability is commonly used, in a Monte-Carlo mode, to perform high fidelity engineering end-to-end simulations for entry, descent, and landing (EDL)¹. Mars-GRAM 2005 has been validated² against Radio Science data, and both nadir and limb data from TES³.

Traditional Mars-GRAM options for representing the mean atmosphere along entry corridors include: (1) TES mapping year 0, with user-controlled dust optical depth and Mars-GRAM data interpolated from NASA Ames Mars General Circulation Model (MGCM)⁴ results driven by selected values of globally-uniform dust optical depth, or (2) TES mapping years 1 and 2, with Mars-GRAM data coming from MGCM results driven by observed TES dust optical depth. From the surface to 80 km altitude, Mars-GRAM is based on NASA Ames MGCM. Above 80 km, Mars-GRAM is based on the University of Michigan Mars Thermospheric General Circulation Model (MTGCM)⁵.

MGCM results that were used for Mars-GRAM with MapYear=0 were from a MGCM run with a fixed value of $\tau=3$ for the entire year at all locations. This choice of data has led to discrepancies that have become apparent during recent sensitivity studies for MapYear=0 and large optical depths. Unrealistic energy absorption by time-invariant atmospheric dust leads to an unrealistic thermal energy balance on the polar caps. The outcome is an inaccurate cycle of condensation/sublimation of the polar caps and, as a consequence, an inaccurate cycle of total atmospheric mass and global-average surface pressure. Under an assumption of unchanged temperature profile and hydrostatic equilibrium, a given percentage change in surface pressure would produce a corresponding percentage change in density at all altitudes. Consequently, the final result of a change in surface pressure is an imprecise atmospheric density at all altitudes.

MARS-GRAM 2010 ADJUSTMENT FACTORS

In determining a possible solution to this discrepancy Mars-GRAM was evaluated at locations and times of TES limb observations, and adjustment factors (ratio of observed TES density to Mars-GRAM density) were determined. The adjustment factors $[F(z, \text{Lat}, L_s)]$ were expressed as a function height (z), Latitude (Lat) and areocentric solar longitude (L_s). For altitudes above 80 km, Mars-GRAM (MTGCM) densities were compared to aerobraking densities measured by MGS, ODY, and MRO. For Mars-GRAM 2010, MGCM and MTGCM data values are modified by these adjustment factors.

Adjustment Factor Requirements

The adjustment factors generated by this process had to satisfy the gas law: $p = \rho RT$ as well as the hydrostatic relation: $dp/dz = -\rho g$. If T is assumed to be unchanged and both p and ρ are adjusted by a common factor, F , both relations are preserved. This adjustment factor, F , is applied to the daily mean MGCM density and pressure (0-80 km) and MTGCM density and pressure (above 80 km). The pressure scale height (RT/g) is unchanged by this process. However, since the pressure has been changed by the adjustment factor, the height of the 1.26 nbar pressure level, referred to as ZF in Mars-GRAM, has also been changed.

The daily mean MGCM or MTGCM density, DTA0, and the daily mean MGCM or MTGCM pressure, PTA0, depend on height (z), latitude (Lat), solar longitude (L_s), dust amount (τ), and solar activity parameter (F_{10}). The adjusted values of DTA0' and PTA0' are computed from the adjustment factors F using the following equations:

$$\text{DTA0}' = \text{DTA0} * F(z, \text{Lat}, L_s) \quad (1)$$

$$\text{PTA0}' = \text{PTA0} * F(z, \text{Lat}, L_s) \quad (2)$$

where the adjustment factor F has been determined as described above.

Adjustment factors F are also used to adjust ZF by the relation:

$$ZF' = ZF + H \ln(F) \quad (3)$$

where H is local pressure scale height.

Development of MTGCM Factors

The Mars-GRAM density and pressure need to be consistent at 80 km, where the transition from MGCM to MTGCM data occurs. Thus, the assumption was made that $F(80, \text{Lat}, L_s)$ for the MTGCM data had to be the same as the adjustment factor at 80 km for the MGCM data. After adjustment factors $F(80, \text{Lat}, L_s)$ were determined from the MGCM analysis, they were used to determine MTGCM adjustment factors by use of the following equation:

$$F(z, \text{Lat}, L_s) = F(80, \text{Lat}, L_s) * (1 + A\zeta + B\zeta^2) \quad (4)$$

where the height parameter $\zeta = (z - 80)$ and the coefficients A and B depend on Lat and L_s .

Final adjustment factors $F(z, \text{Lat}, L_s)$ for MTGCM data were implemented into Mars-GRAM and a validation run comparing Mars-GRAM 2010 vs. MGS, ODY, and MRO aerobraking data from the Planetary Data System (PDS) was completed. Any residual variation of aerobraking density about mean values that became apparent during this process was used to update the height dependence of Mars-GRAM perturbation standard deviations.

IMPROVEMENT IN MARS-GRAM 2010 RESULTS

Improvement of Mars-GRAM 2010 at Lower Altitudes

Application of adjustment factors for the MGCM data yields improved comparisons between Mars-GRAM and TES limb data, as shown by density ratios (Mars-GRAM/TES Limb) given in Figure 1. Prior to adjustment these density ratios were as low as 0.65 near 60 km.

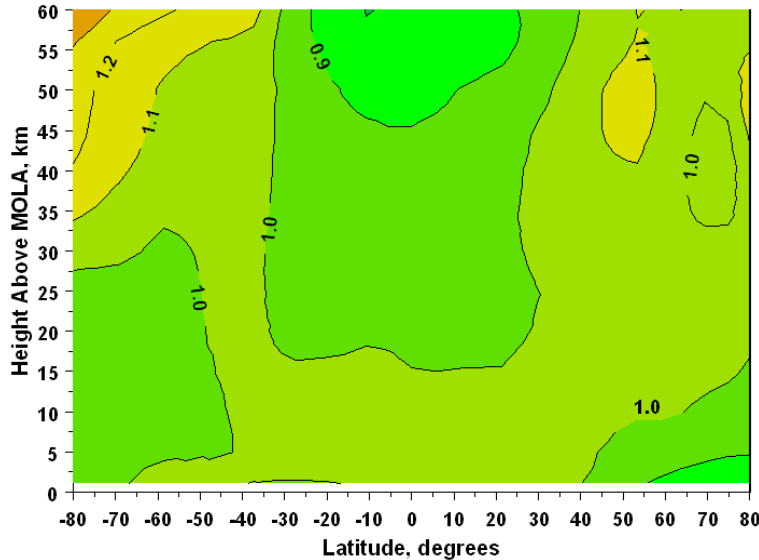


Figure 1. Latitude-Height Contours of Density Ratio (Mars-GRAM/TES Limb) After Application of MGCM Adjustment Factors

Mars-GRAM 2005 and Mars-GRAM 2010 MapYear = 0 results have also been compared for three locations at Local True Solar Time (LTST) 2 and 14.

- Location 1 (L1) = 22.5° S, 180° E, $L_s = 90 \pm 5$, $\tau = .11$
- Location 2 (L2) = 22.5° S, 180° E, $L_s = 75 \pm 5$, $\tau = .12$
- Location 3 (L3) = 2.5° N, 180° E, $L_s = 210 \pm 5$, $\tau = 2.65$ *Dust Storm case*

Figure 2 provides the density ratios of Mars-GRAM to TES for Mars-GRAM 2005. As Figure 3 shows, the application of the adjustment factor in Mars-GRAM 2010 results in ratios of approximately 1 at lower altitudes.

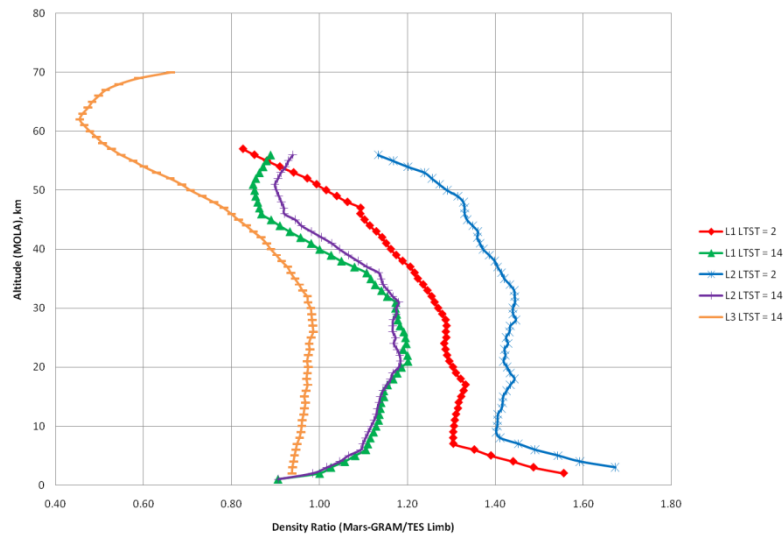


Figure 2. Density Ratio (Mars-GRAM/TES) for Mars-GRAM 2005

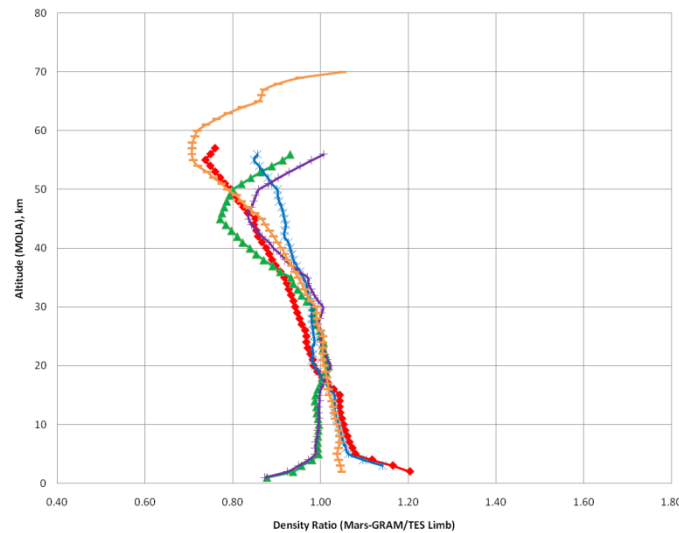


Figure 3. Density Ratio (Mars-GRAM/TES) for Mars-GRAM 2010

At the higher altitudes, Mars-GRAM 2010 results have corrected the effect of the underestimated dust aloft in the MGCM. At location 3, the Mars-GRAM 2010 density ratio has shifted

closer to 1. This demonstrates that the addition of adjustment factors to Mars-GRAM 2010 has improved the results for the MapYear = 0 cases for large tau values.

Improvement of Mars-GRAM 2010 at Aerobraking Altitudes

Mars-GRAM modeled data output has improved at aerobraking altitudes by adding MTGCM adjustment factors which included height parameters and thermosphere coefficients. Improvement has been quantified by examining all of the profile data density ratios for each PDS orbiter. The 99th percentile profile shows the most extreme cases of ratio values while eliminating outliers that do not contribute to the standard profile. Density ratios for the old and updated Mars-GRAM versions will be shown versus height and latitude globally for Mars; these results will show the variability in certain regions on the red planet. All of these results will show that the updated Mars-GRAM is producing more realistic results, which will assist in future autonomous aerobraking procedures.

All of the density ratios from the PDS profile datasets are shown in Figures 4, 5, and 6. Each of these figures shows the density ratio of the PDS density to the Mars-GRAM output density versus height, with the blue lines representing the old Mars-GRAM output and the red lines showing the updated Mars-GRAM 2010 output using the thermosphere coefficients. Each one of the datasets showed an improvement with the ratio values for the latest version of Mars-GRAM. The MGS/Mars-GRAM density ratio originally was an average 2.6 with a maximum value of 16.1, but the updated Mars-GRAM 2010 ratio data averaged 1.8 with a maximum value of 10.7. The initial MRO/Mars-GRAM density ratio reached a maximum of 10.0 and averaged 2.0, whereas the new ratio only reached a maximum of 3.6 and averaged 0.9—close to the optimal 1.0 ratio. The Odyssey/Mars-GRAM ratio exceeded all of the other ratios with a maximum ratio of 39 but had an average of 3.9, which means that there were several outlying profiles that skewed the average profile. However, the newly-modeled ODY/Mars-GRAM 2010 ratio only reached a maximum of 8.2 with an average of 0.99. As these results show, the updated Mars-GRAM 2010 with MTGCM adjustment factors including thermosphere coefficients greatly improves the results of the modeled data when compared to observed data.

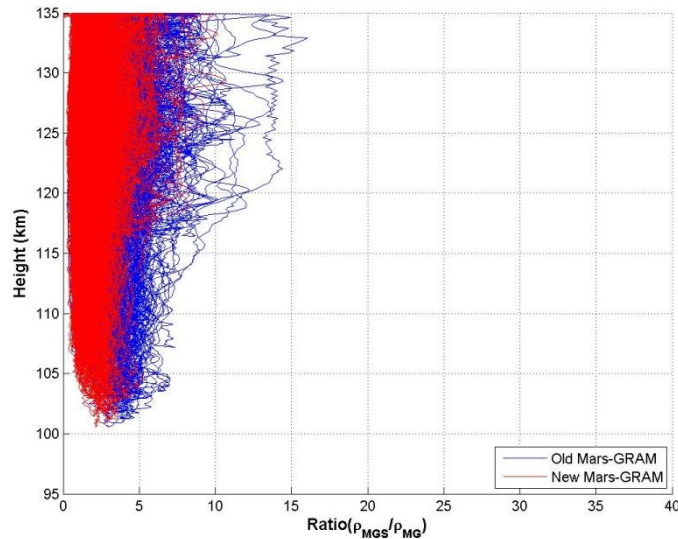


Figure 4. Density Ratios of MGS data to the New and Old Mars-GRAM Output Data

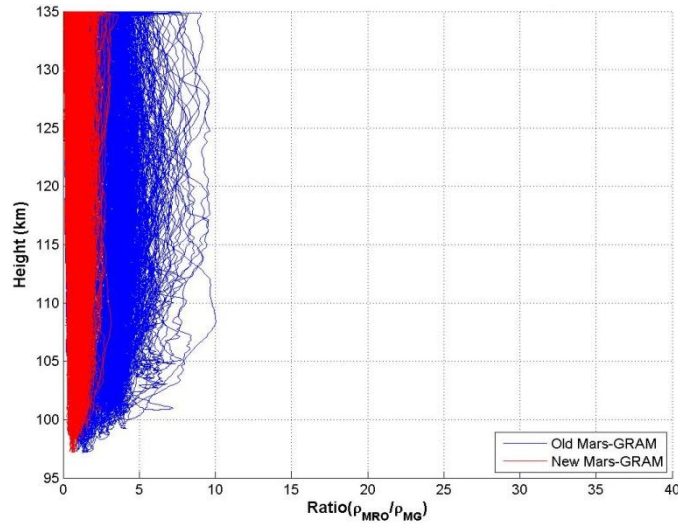


Figure 5. Density Ratios of MRO data to the New and Old Mars-GRAM Output Data

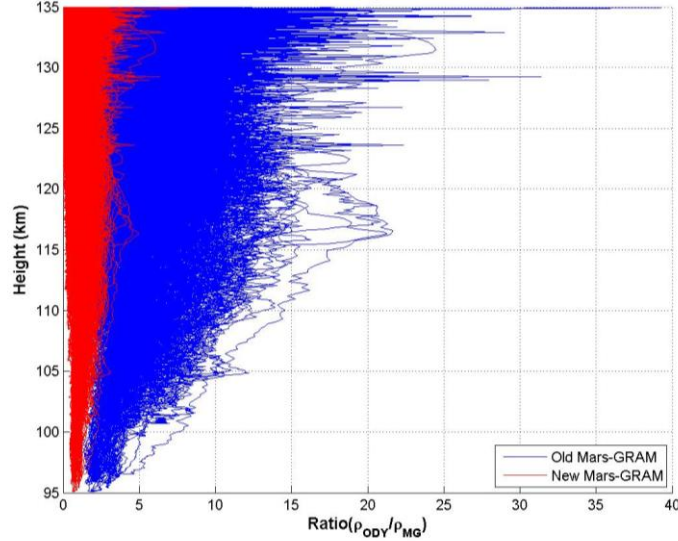


Figure 6. Density Ratios of ODY data to the New and Old Mars-GRAM Output Data

Taking the 99th percentile of all the density profiles illustrates the significant change the updated Mars-GRAM 2010 has on the profile density ratios. As shown in Figure 7, the least amount of change was observed in the MGS data over the 99th percentile profile data, with an overall change of 2.0 units across the altitude range. The MRO data showed a significant improvement from the old version of Mars-GRAM, reducing the higher altitude ratios from 6.0 to close to the optimal value of 1.0 on the updated data. However, the greatest change in ratio values occurred with the Odyssey data where the older data reached values close to 20.0 but the newer data brought the ratios down to a range between less than 1.0 to over 4.0 at the higher altitudes. All of the ratio values of the datasets improved from the old Mars-GRAM data output to the updated Mars-GRAM 2010 version; therefore, the inclusion of MTGCM adjustment factors has shown to be valid in providing more realistic output to be used in future endeavors.

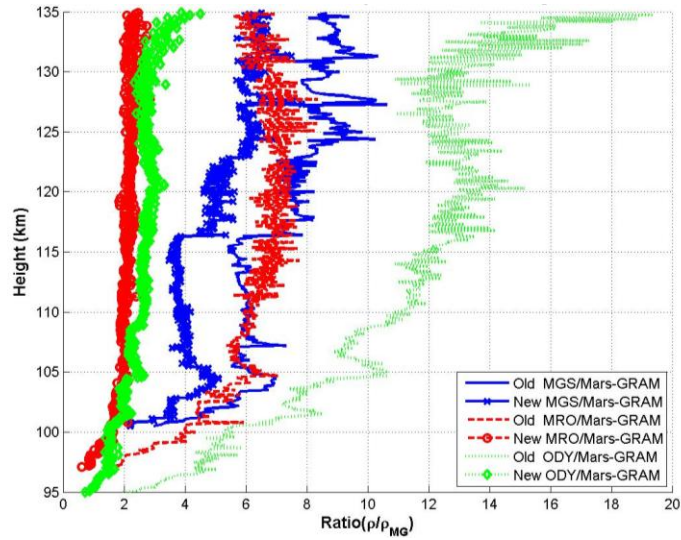


Figure 7. The 99th percentile density ratios of the profile data from MGS, MRO, and ODY to Mars-GRAM 2010 output versus height

Although autonomous aerobraking procedures are sensitive to density values at certain altitude levels, showing the density ratio values according to latitude is also beneficial for mission planning operations. Figures 8 and 9 show the ratio of the observed density values to the Mars-GRAM output values for the old version and the updated Mars-GRAM 2010 version versus height and Mars latitude. Before the MTGCM adjustment factors including thermosphere coefficients were added to the Mars-GRAM code (Figure 8), the ratio values were higher than the optimal value of 1.0, especially at locations towards the poles. The contour lines are very tight near the poles, meaning lots of variability exists with the comparisons. In the updated plot shown in Figure 9, a large area of the map is covered with the 1.0 ratio value, especially between -30°S and 15°N . Although a large discrepancy of ratio values still exist towards the poles, the variability has decreased with the inclusion of the adjustment factors. Improvement in density ratio values across latitudes can be beneficial for planning autonomous aerobraking procedures on Mars.

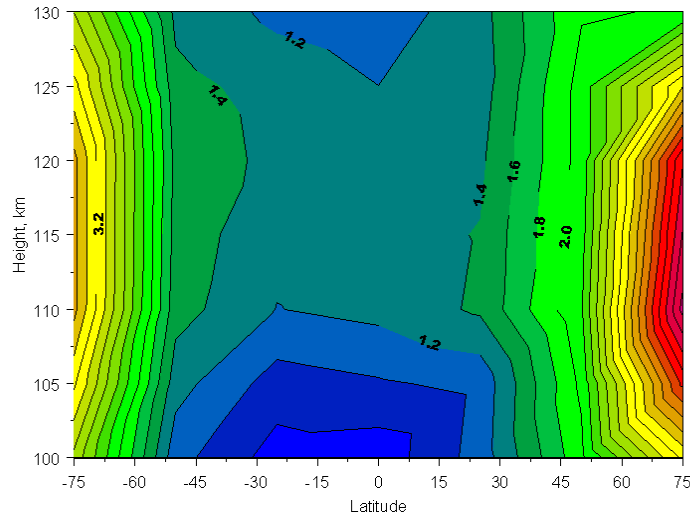


Figure 8. Contour plots of the ratio of observed PDS density values to Mars-GRAM output values (before adjustment) versus height and latitude.

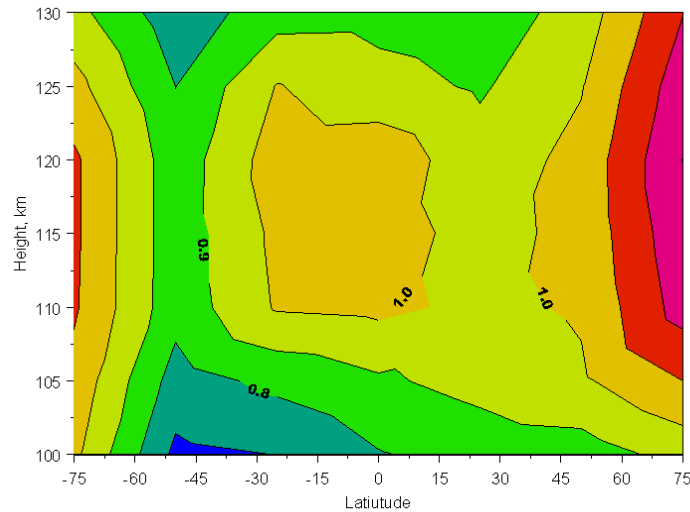


Figure 9. Contour plots of the ratio of observed PDS density values to Mars-GRAM 2010 output values (after adjustment) versus height and latitude.

CONCLUSION

Mars-GRAM 2010 has been developed, validated and is ready for distribution. Mars-GRAM in the past has been export controlled (EAR-99), but is now classified as publically available. This change in distribution classification has increased the availability of Mars-GRAM 2010 to users. Mars-GRAM 2010 has been updated to Fortran 90/95. Mars-GRAM 2010 now includes adjustment factors that are used to alter the input data from MGCM and MTGCM for the Mapping year 0 (user-controlled dust) case. The greatest adjustment occurs at large optical depths such as $\tau > 1$. The addition of the adjustment factors has led to better correspondence to TES Limb data from 0-60 km as well as better agreement with MGS, Odyssey and MRO data at approximately 90-130 km. Improved simulations utilizing Mars-GRAM 2010 are vital to developing the onboard atmospheric density estimator for the Autonomous Aerobraking Development Plan.

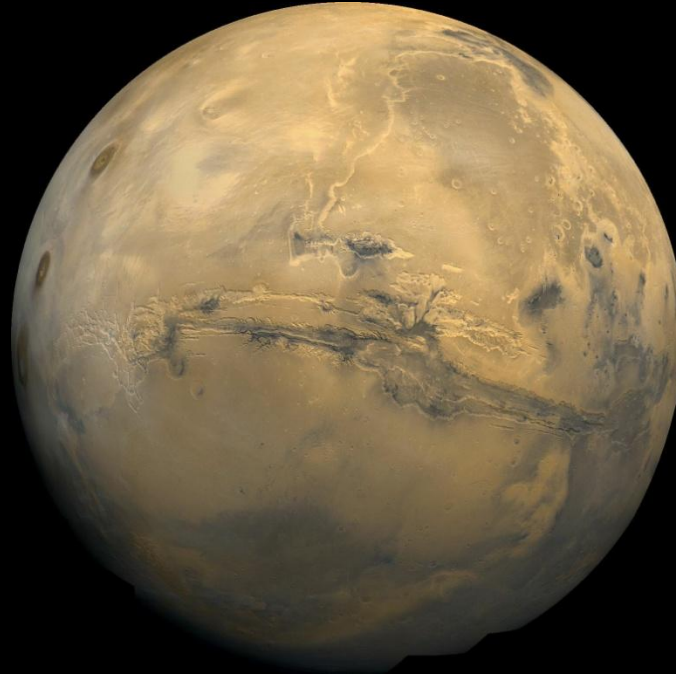
ACKNOWLEDGMENTS

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NASA MSFC Autonomous Aerobraking Tasks

- Compare Mars-GRAM with MGS, Odyssey and MRO data
 - Release an updated version of Mars-GRAM upon completion of comparison study
- Coordinate with others in the Autonomous Aerobraking Team using Mars-GRAM 2010 Density Output
- Generate Density Data Sets for "Aerobraking Design Reference Missions" using Titan-GRAM and Venus-GRAM
 - Altitude profiles (both vertical and along trajectory)
 - Include GRAM perturbations (tides, gravity waves, etc.)
 - Provide density and scale height values for analysis by Bob Tolson

Mars Global Reference Atmospheric Model (Mars-GRAM)



- Engineering-level atmospheric model widely used for diverse mission applications
- Mars-GRAM's perturbation modeling capability is commonly used, in a Monte-Carlo mode, to perform high fidelity engineering end-to-end simulations for entry, descent, and landing (EDL)¹
- Mars-GRAM has been utilized during previous aerobraking operations:
 - Mars Global Surveyor (MGS)
 - Mars Odyssey (ODY)
 - Mars Reconnaissance Orbiter (MRO)
- Mars-GRAM was used during the Mars Aerocapture System Study (MASS) as well as the Aerocapture Technology Assessment Group (TAG)
- From the surface to 80 km altitude, Mars-GRAM is based on NASA Ames Mars General Circulation Model (MGCM)²
 - Mars-GRAM and MGCM use surface topography from Mars Global Surveyor Mars Orbiter Laser Altimeter (MOLA), with altitudes referenced to the MOLA areoid, or constant potential surface
- Above 80 km, Mars-GRAM is based on the University of Michigan Mars Thermospheric General Circulation Model (MTGCM)³

Mars-GRAM Atmospheric Options

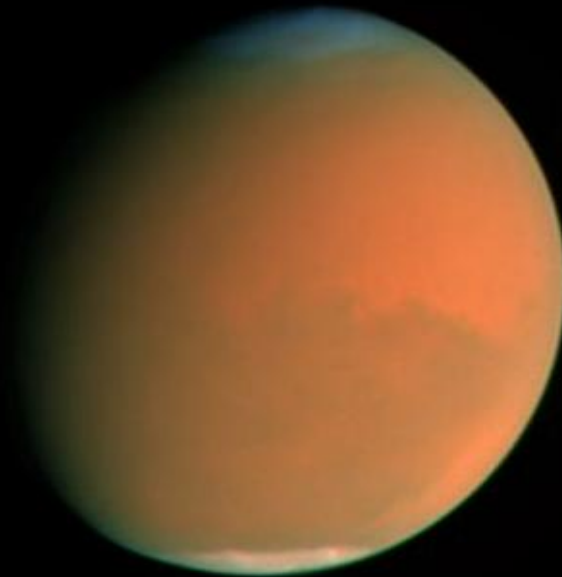
Mars-GRAM options for representing the mean atmosphere along entry corridors:

- Thermal Emission Spectrometer (TES) Mapping Years 1 and 2, with Mars-GRAM data coming from MGCM model results driven by observed TES dust optical depth
- TES Mapping Year 0, with user-controlled dust optical depth and Mars-GRAM data interpolated from MGCM model results driven by selected values of globally-uniform dust optical depth
- Option to read and use any auxiliary profile of temperature and density versus altitude



Sunset over Gusev Crater taken by Spirit
(Image Courtesy of: NASA/JPL/Texas A&M/Cornell)

Increasing the Accuracy of Mars-GRAM



September 4, 2001

(Image Courtesy of: NASA/JPL)



Background

- It has been discovered that the Mars Global Reference Atmospheric Model (Mars-GRAM) when used for sensitivity studies for TES MapYear=0 and large optical depth values such as $\tau=3$ is less than realistic
 - MGCM results that were used for Mars-GRAM with MapYear=0 were from a MGCM run with a fixed value of $\tau=3$ for the entire year at all locations
 - Unrealistic energy absorption by uniform atmospheric dust leads to an unrealistic thermal energy balance on the polar caps
 - Outcome is an inaccurate cycle of condensation/sublimation of the polar caps and, as a consequence, an inaccurate cycle of total atmospheric mass and global-average surface pressure
 - Under an assumption of unchanged temperature profile and hydrostatic equilibrium, a given percentage change in surface pressure would produce a corresponding percentage change in density at all altitudes
 - Consequently, the final result of a change in surface pressure is an imprecise atmospheric density at all altitudes
-



Mars-GRAM 2010 Adjustment Factors

- Mars-GRAM was evaluated at locations and times of TES limb observations, and adjustment factors (ratio of observed TES density to Mars-GRAM density) were determined
- Adjustment factors $[F(z, \text{Lat}, \text{Ls})]$ were expressed as a function of height (z), Latitude (Lat) and areocentric solar longitude (Ls)
- For altitudes above 80 km, Mars-GRAM MTGCM densities were compared to aerobraking densities measured by Mars Global Surveyor (MGS), Mars Odyssey (ODY), and Mars Reconnaissance Orbiter (MRO).



Adjustment Factor Requirements

- Adjustment factors generated by this process had to satisfy the gas law: $p = \rho RT$ as well as the hydrostatic relation: $dp/dz = -\rho g$.
- T is assumed to be unchanged and both p and ρ are adjusted by a common factor, F , preserving both relations
- Adjustment factor, F , is applied to the daily mean MGCM density and pressure (0-80 km) and MTGCM density and pressure (above 80 km)
- Pressure scale height (RT/g) is unchanged by this process
- Pressure has been changed by the adjustment factor, thus the height of the 1.26 nbar pressure level, referred to as ZF in Mars-GRAM, has changed



Adjustment Factor Computations

- The daily mean MGCM or MTGCM density, DTA0, and the daily mean MGCM or MTGCM pressure, PTA0, depend on z , Lat, Ls, tau, and solar activity parameter (F10)
- The adjusted values of DTA0' and PTA0' are computed from the adjustment factors F using the following equations:

$$\text{DTA0}' = \text{DTA0} * F(z, \text{Lat}, \text{Ls})$$

$$\text{PTA0}' = \text{PTA0} * F(z, \text{Lat}, \text{Ls})$$

where the adjustment factor F has been determined as described above

- Adjustment factors F are also used to adjust ZF by the relation:

$$ZF' = ZF + H \ln(F)$$

where H is local pressure scale height



Development of MTGCM Factors

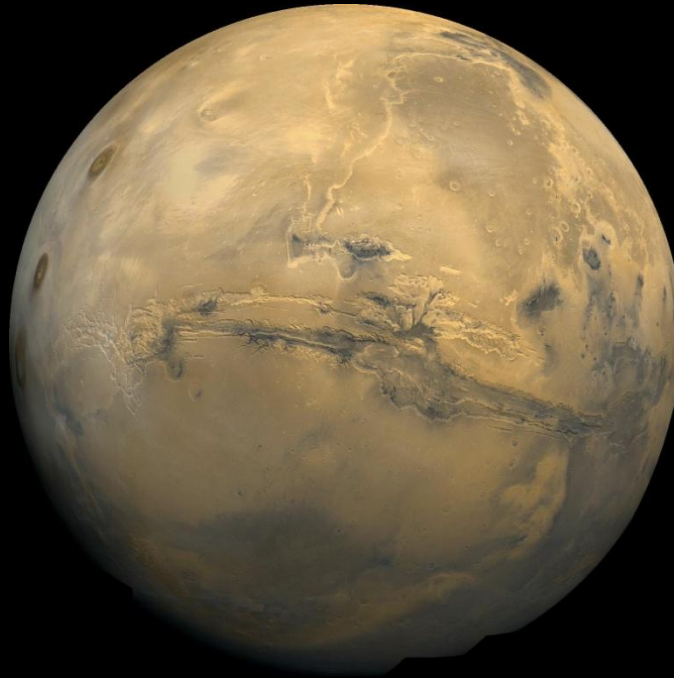
- Mars-GRAM density and pressure need to be consistent at 80 km, where the transition from MGCM to MTGCM data occurs
 - Assumption was made that $F(80, \text{Lat}, \text{Ls})$ for the MTGCM data had to be the same as the adjustment factor at 80 km for the MGCM data
- After adjustment factors $F(80, \text{Lat}, \text{Ls})$ were determined from the MGCM analysis, they were used to determine MTGCM adjustment factors by use of the following equation:

$$F(z, \text{Lat}, \text{Ls}) = F(80, \text{Lat}, \text{Ls}) * (1 + A\zeta + B\zeta^2)$$

where the height parameter $\zeta = (z - 80)$ and the coefficients A and B depend on Lat and Ls

- Final adjustment factors $F(z, \text{Lat}, \text{Ls})$ for MTGCM data were implemented into Mars-GRAM and a validation run comparing Mars-GRAM vs. MGS, ODY, and MRO aerobraking data was completed
 - Any residual variation of aerobraking density about mean values that became apparent during this process was used to update the height dependence of Mars-GRAM perturbation standard deviations
-

Improvement In Mars-GRAM 2010 Results



(Image Courtesy of: NASA/JPL)

Improvement of Mars-GRAM 2010 at Lower Altitudes



- Application of adjustment factors for the MGCM data yields improved comparisons between Mars-GRAM and TES limb data, as shown by density ratios (Mars-GRAM/TES Limb) given in Figure 1
- Prior to adjustment these density ratios were as low as 0.65 near 60 km

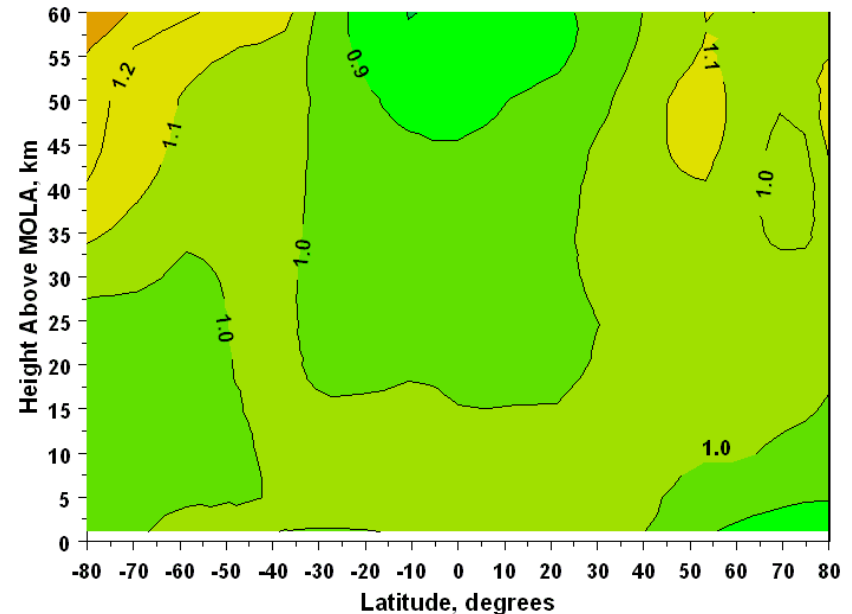


Figure 1. Latitude-Height Contours of Density Ratio (Mars-GRAM/TES Limb) After Application of MGCM Adjustment Factors

Comparison Study between Mars-GRAM and TES data



- Mars-GRAM 2005 and Mars-GRAM 2010 MapYear = 0 results have been compared for three locations at Local True Solar Time (LTST) 2 and 14
 - Location 1 (L1) = 22.5° S, 180° E, $L_s = 90 \pm 5$, $\tau = .11$
 - Location 2 (L2) = 22.5° S, 180° E, $L_s = 75 \pm 5$, $\tau = .12$
 - Location 3 (L3) = 2.5° N, 180° E, $L_s = 210 \pm 5$, $\tau = 2.65$ *Dust Storm case*
- Figure 2 provides the density ratios of Mars-GRAM to TES for Mars-GRAM 2005
- As Figure 3 shows, the application of adjustment factors in Mars-GRAM 2010 results in ratios of approximately 1 at lower altitudes
- At the higher altitudes, Mars-GRAM 2010 results have corrected the effect of the underestimated dust aloft in the MGCM

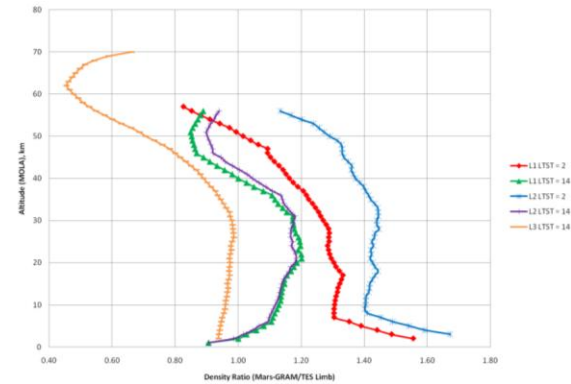


Figure 2. Density Ratio (Mars-GRAM/TES) for Mars-GRAM 2005

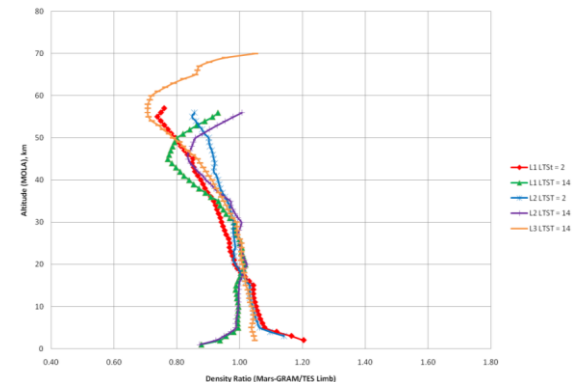


Figure 3. Density Ratio (Mars-GRAM/TES) for Mars-GRAM 2010

Improvement of Mars-GRAM 2010 at Aerobraking Altitudes



- Before the addition of MTGCM adjustment factors to the Mars-GRAM code (Figure 4)
 - Ratio values were higher than the optimal value of 1.0, especially at locations towards the poles
 - Contour lines are very tight near the poles, denoting increased variability
- With the addition of MTGCM adjustment factors (Figure 5)
 - A large area of the map is covered with the 1.0 ratio value, especially between -30°S and 15°N
 - Large discrepancy of ratio values still exist towards the poles, variability has decreased
- Improvement in density ratio values across latitudes can be beneficial for planning autonomous aerobraking procedures on Mars

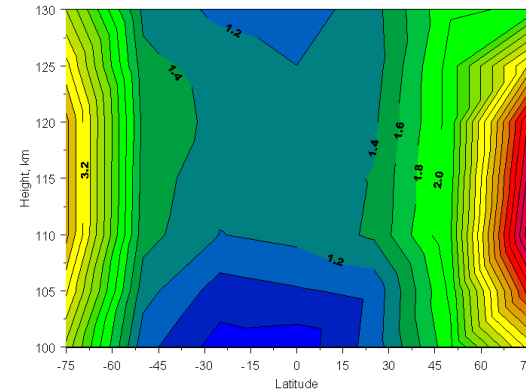


Figure 4. Contour plots of the ratio of observed PDS density values to Mars-GRAM output values (before adjustment) versus height and latitude.

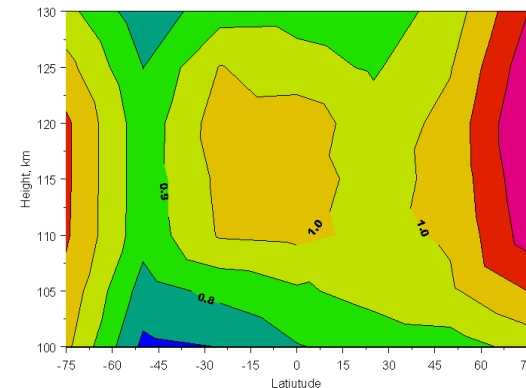


Figure 5. Contour plots of the ratio of observed PDS density values to Mars-GRAM 2010 output values (after adjustment) versus height and latitude.

Comparison Study between Mars-GRAM and MGS, MRO and Odyssey Data



- Each dataset showed an improvement in the density ratio values for Mars-GRAM 2010
- MGS/Mars-GRAM Density Ratio
 - Originally averaged 2.6 with a maximum value of 16.1,
 - Updated Mars-GRAM 2010 averaged 1.8 with a maximum value of 10.7
- MRO/Mars-GRAM Density Ratio
 - Originally averaged 2.0 with a maximum value of 10.0
 - Updated Mars-GRAM 2010 averaged 0.9 with a maximum value of 3.6
- Odyssey/Mars-GRAM Density Ratio
 - Originally averaged 3.9 with a maximum value of 39
 - Updated Mars-GRAM 2010 averaged 0.99 with a maximum value of 8.2

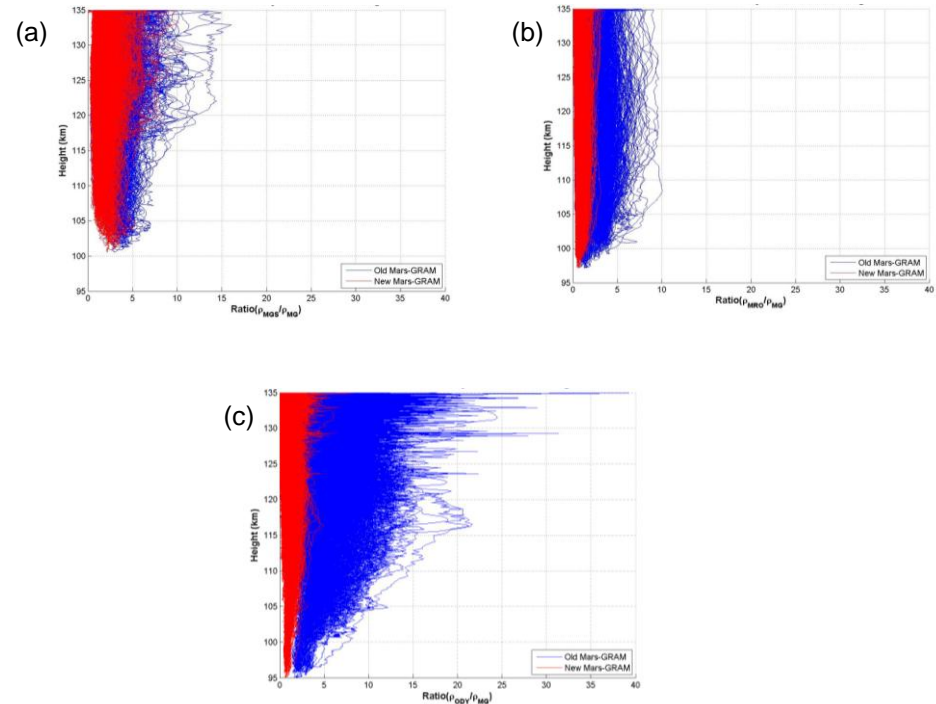


Figure 6. Density Ratios of (a) MGS (b) MRO and (c) Odyssey data to the New (Red) and Old (Blue) Mars-GRAM Output Data



Conclusions

- Mars-GRAM 2010 has been developed, validated and is ready for distribution.
- Adjustment factors are used to adjust the input data from MGCM and MTGCM for Mapping Year 0 (user-controlled dust) case
 - Greatest adjustment at large optical depth ($\tau > 1$)
 - Better correspondence to TES Limb data (0-60 km)
 - Better agreement with MGS, Odyssey and MRO data (~ 90-130 km)
- Improved simulations utilizing Mars-GRAM 2010 are vital to developing the onboard atmospheric density estimator for the Autonomous Aerobraking Development Plan



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